INTERBALL–1 OBSERVATIONS OF THE PLASMASPHERIC EMISSIONS RELATED TO TERRESTRIAL "CONTINUUM" RADIO EMISSIONS

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Abstract

Electromagnetic radio emissions of the inner magnetospheric regions have been observed and analyzed by the AKR–X spectrum analyzer in the frequency range 100–1500 kHz, at the beginning (August–October 1995) and at the end (August–October 2000) of the INTERBALL–1 operation at the perigees of the satellite (1.1–1.5 R_E). Observations show that electromagnetic modes (Z and LO escaping mode) originating at altitudes of 500–4000 km are related to subauroral non–thermal continuum emissions (SANE) and to recently discovered kilometric continuum emissions [Hashimoto et al., 1999b].

We find a difference between the spectral character of these emissions at the minimum (1995) and maximum (2000) of Solar activity. During the period of the quiet Sun the escaping emission (apparently LO–mode) was regularly observed, however only local modes have been recorded during the period of the active Sun. SANE was not observed after mid-1998 till the maximum of Solar activity. The analysis of the time periods of all "continuum" observations, beginning with the discovery of equatorial ones by Brown [1973], shows that all these emissions manifest themselves close to the minimum of Solar activity (approximately 2.5 years before and after). The physical processes in the inner magnetosphere connected with the Solar activity seem to affect the "continuum" radio emissions at the time of quiet and active Sun.

1 Introduction

Non–thermal terrestrial "continuum" radio emission was discovered below 100 kHz by Brown [1973] and first described and discussed in detail by Gurnett and Shaw [1973] and Gurnett [1975]. Recent observations of the GEOTAIL satellite show the presence of

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a new kind of "continuum" in the frequency range 100–800 kHz. This emission called "kilometric continuum" at its high frequency boundary is near the frequencies of the "subauroral continuum" discovered at first by the PROGNOZ–10 satellite at frequencies 992 and 1500 kHz [Kuril'chik et al., 1988, 1992a] and investigated in more detail by the INTERBALL–1 (INT–1) satellite which operated in 1995–2000. The INT–1 satellite was placed on a very extended elliptic orbit with an initial apogee at a geocentric distance of about 32 R_E, at a latitude of about 40°N, and the orbital period was about 91 hours.

The experiment "Analyzer of Kilometric Radio emissions" (AKR–X) on board of the INT–1 satellite enabled the observation of radio emissions of the terrestrial magnetosphere and Solar sporadic radio emissions in the frequency range 100–1500 kHz by using a practically uninterrupted monitoring of these emissions during the 5 years of the gradual transition from the quite to active Sun.

2 Observations

The initial perigee (August 1995) at a latitude of 40°N reached its maximum value about 5 R_E at the latitude 10°S in April 1998 and then gradually decreased to 1.1 R_E at the latitude of about 5°N at the end of satellite operation (October 2000).

This permitted the registration of emissions of the inner magnetosphere during periods of the quiet Sun (August–September 1995) and at the maximum of Solar activity (July–October 2000).

Figure 1 a–d shows examples of the registration of these emissions in August–September 1995 where we note a gradual decrease in the local "resonant" frequency when the geocentric distance increases. At each frequency the registration begins in the inner magnetosphere closer to the Earth at a rather high magnetic latitude λ_m. In this region of higher magnetic field strength and plasma density the combination of Z– and LO–modes is observed with a pronounced maximum of the signal in the region between the local plasma and the upper hybrid frequency (see Figures 1a and 1b, for example). At larger geocentric distances and closer to the magnetic equator only escaping emission (apparently LO–mode) is recorded with a specific smooth character and a modulation by the satellite rotation (periodicity about 120 s), which gives an evidence that the emission is observed outside of its source region.

The general common situation of registration of these inner magnetospheric emissions in August–October 1995 (first 15 orbital turns of the satellite) is presented in Figure 2. Note that the distribution of localization at frequency "resonant" regions must be symmetric relative to the magnetic equator. Two facts are important: first, emission is present, escaping the inner magnetosphere, practically at each orbit (variations of the intensity in time are also observed, which is evident from the comparison, see e.g. Figures 1a and 1b), and second, concentration of this escaping emission at the magnetic equator (at least at frequencies of the kilometric "continuum", i.e. 252, 500 and 749 kHz). The origin regions of this "continuum" are situated at altitudes between 1500–4000 km in agreement with Hashimoto et al. [1999b], where emission "comes from deep inside the plasmasphere at

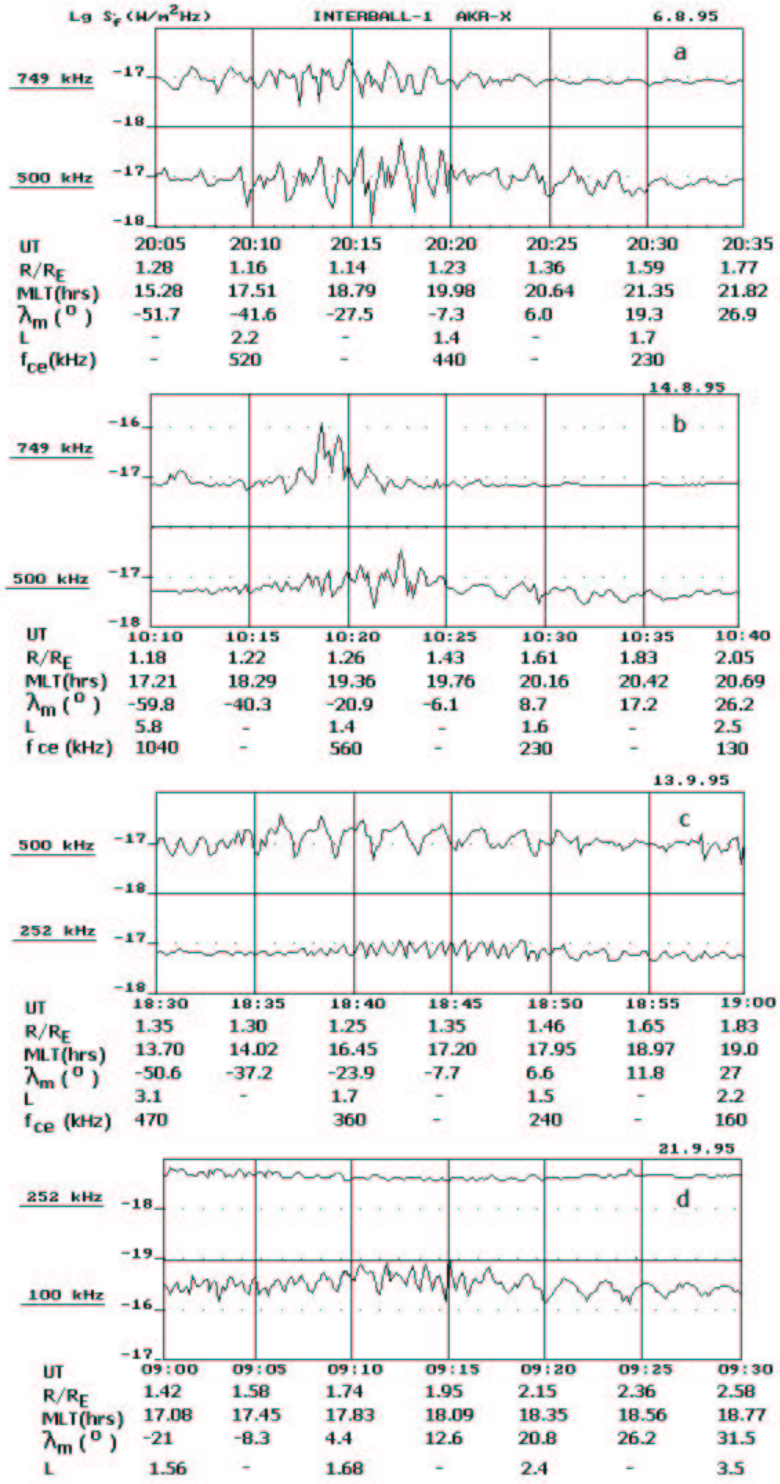

Figure 1: Electromagnetic emissions of the inner magnetosphere detected by the INT–1 satellite on (a) August 6, (b) August 14, (c) September 13 and (d) September 21, 1995. In the course of gradual increase of the geocentric distance at different frequencies, at first localized Z– and LO–modes and later escaping LO–modes are registered.

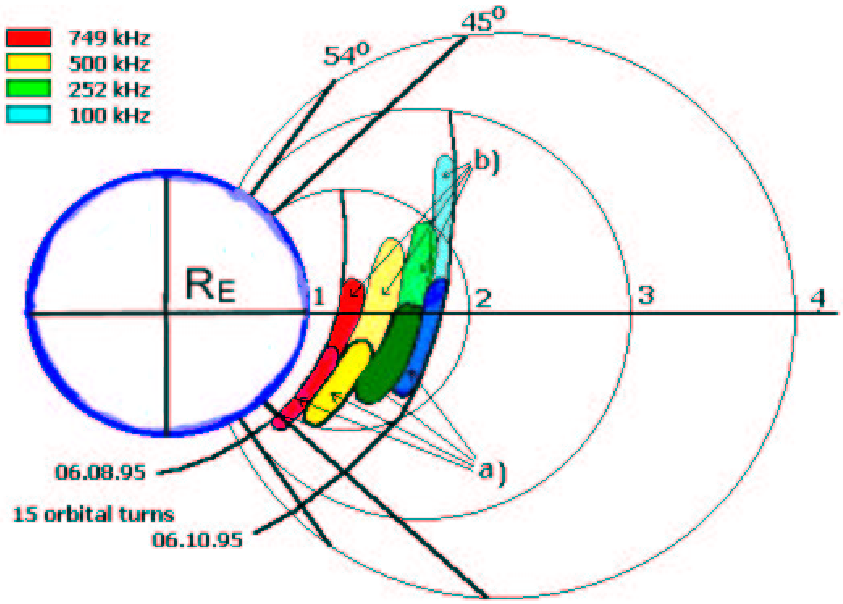

Figure 2: The stratification of different frequency resonant regions at first passages of the inner magnetosphere region by the INT–1 satellite at the perigees of orbit. In region a) local Z– and LO–modes are registered, in regions b) an escaping (LO)–mode is observed with maximum intensity closer to the magnetic equator.

an altitude of less than a few thousand kilometers in the topside equatorial region of the Earth's ionosphere".

Another characteric of the emissions of the inner magnetosphere was observed at the time near the maximum of Solar activity (August–October 2000). All elliptic orbits of the INT–1 satellite were located close to the equatorial plane and had an inclination angle of about 70°. The equatorial position of the satellite allowed the registration of kilometric "continuum" emissions at different distances from Earth.

During the period of gradual decrease of the perigee from January through July 2000, i.e. from 2.4 R_E to 1.6 R_E, no escaping emission (apart from AKR appearance) were detected near the magnetic equator with a level of the flux density larger than about 10^{-18} W/m^{2}Hz.

Figure 3 a–d shows examples of the registration of equatorial inner magnetospheric emissions. All passages of the satellite through this region show only impulsive emissions. Contrary to the quiet sun period, the remarkable peculiarity of these emissions at times of high Solar activity is also the absence of a clear stratification of the frequency "resonant" regions at different distances from the Earth, which is demonstrated in Figure 4. At frequencies of the kilometric "continuum" (252, 500 and 749 kHz) the pronounced maxima of the impulsive signal lie at the magnetic equator and gradually decrease with increasing distance to Earth. Thus, at the period of an active Sun some mechanism exists in suppressing the escape of non–thermal emission.

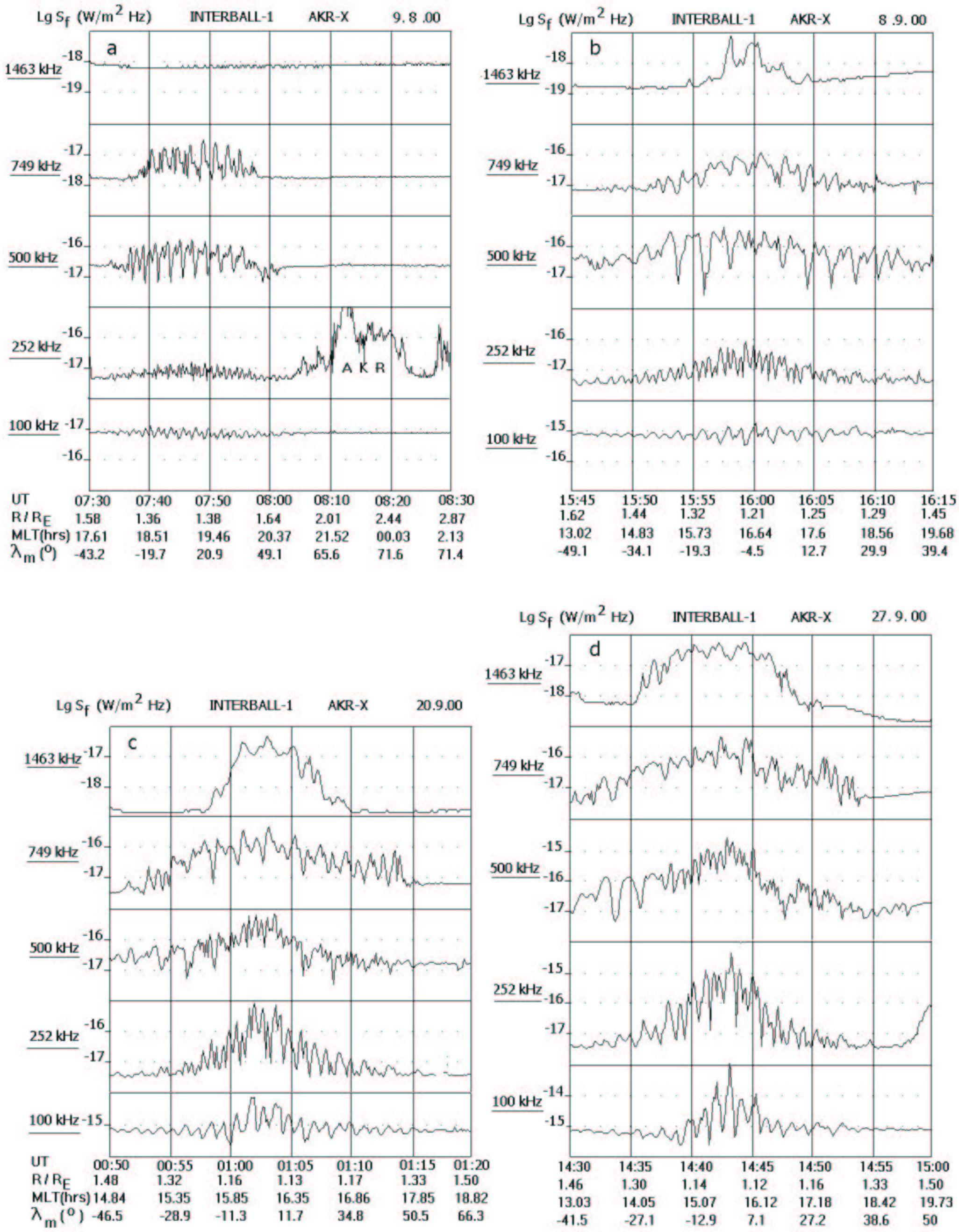

Figure 3: Examples of the registration of terrestrial inner magnetospheric emissions on (a) August 9, (b) September 8, (c) September 20, (d) September 27, 2000, at the perigees of INTERBALL–1 orbital motion. The sequence of registration reflects a change of the character of the signal at different frequencies with the decrease of perigee.

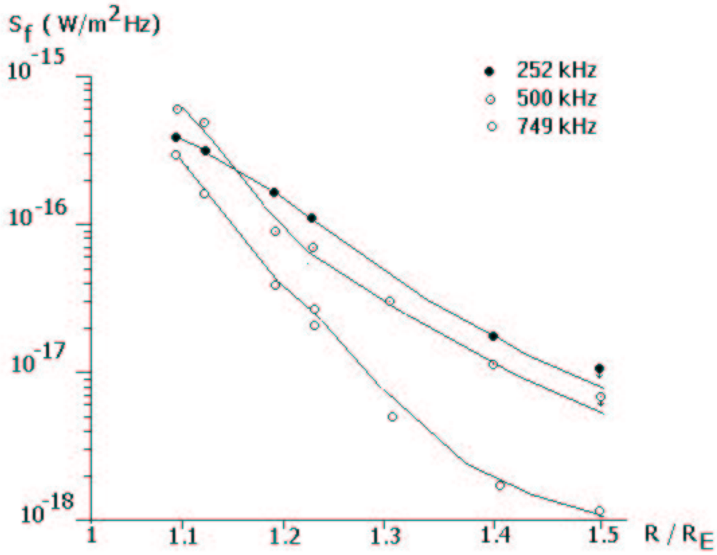

Figure 4: The intensity of local inner magnetospheric emissions at the magnetic equator as a function of geocentric distance.

How does the kilometric "continuum" close behave, if it exists during periods of the quiet Sun? Figure 5 shows examples of "continuum" registration at a frequency of 252 kHz in 1996 (at this time Hashimoto's group discovered and investigated this emission at distances of about 10 R_E).

We note, first of all, the beamed character of the emission. The latitudinal angular extent of beams at geocentric distances 2.4–3.4 R_E is in the range of 1.2°–6°. The propagation direction of emission does not depend on Magnetic Local Time (MLT, see Figure 5) which is in agreement with GEOTAIL data. Figure 6 presents data of the kilometric "continuum" also at 252 kHz during the second half of 1995 and at the beginning of 1996, when the satellite passed the magnetic equator at large geocentric distances comparable with those distances of GEOTAIL registrations.

The events of the kilometric "continuum" were observed more often at the frequency of 252 kHz. GEOTAIL data also showed a maximum of the spectrum (and maximum observed events) near this frequency. Figure 7 demonstrates several rare examples of registrations of "continuum" simultaneously at 252 and 500 kHz and single registrations at frequencies 100 and 500 kHz. No event was observed at 749 kHz at least at the magnetic equator due to the rapid decrease of the corresponding spectrum. The number of events observed by GEOTAIL around this frequency is at least one order of magnitude smaller than at 252 kHz [Hashimoto et al., 1999b].

Also the observation of emission at 1463 kHz (see Figure 3 a–d) very close to Earth (500–1000 km) should be noted here. Apparently this is Z–mode propagating from its source at subauroral latitudes. During the period of the quiet Sun this emission escapes the inner magnetosphere as the so–called subauroral non–thermal emission [Kuril'chik et al., 1997].

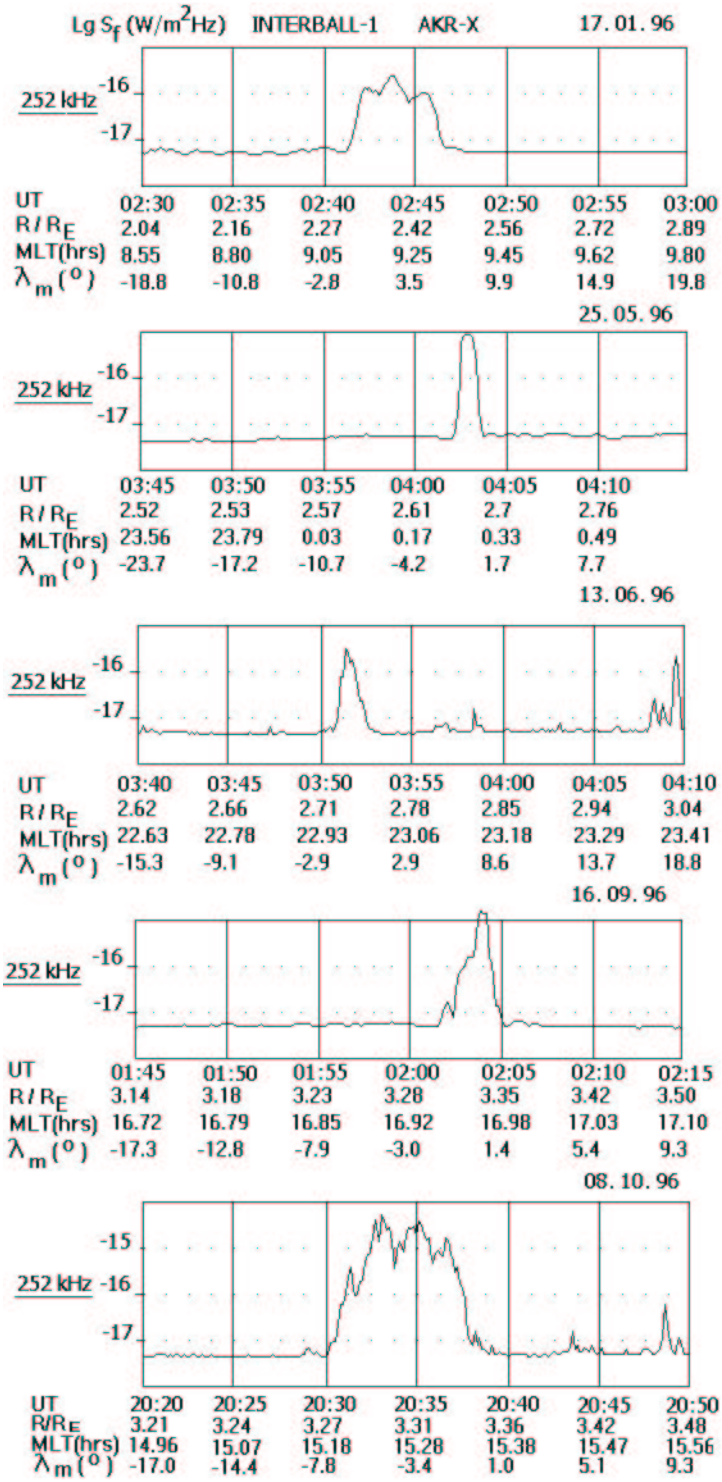

Figure 5: Examples of kilometric "continuum" emission at frequency 252 kHz observed in 1996. The emission has a sharp beamed character in the plane of the magnetic equator.

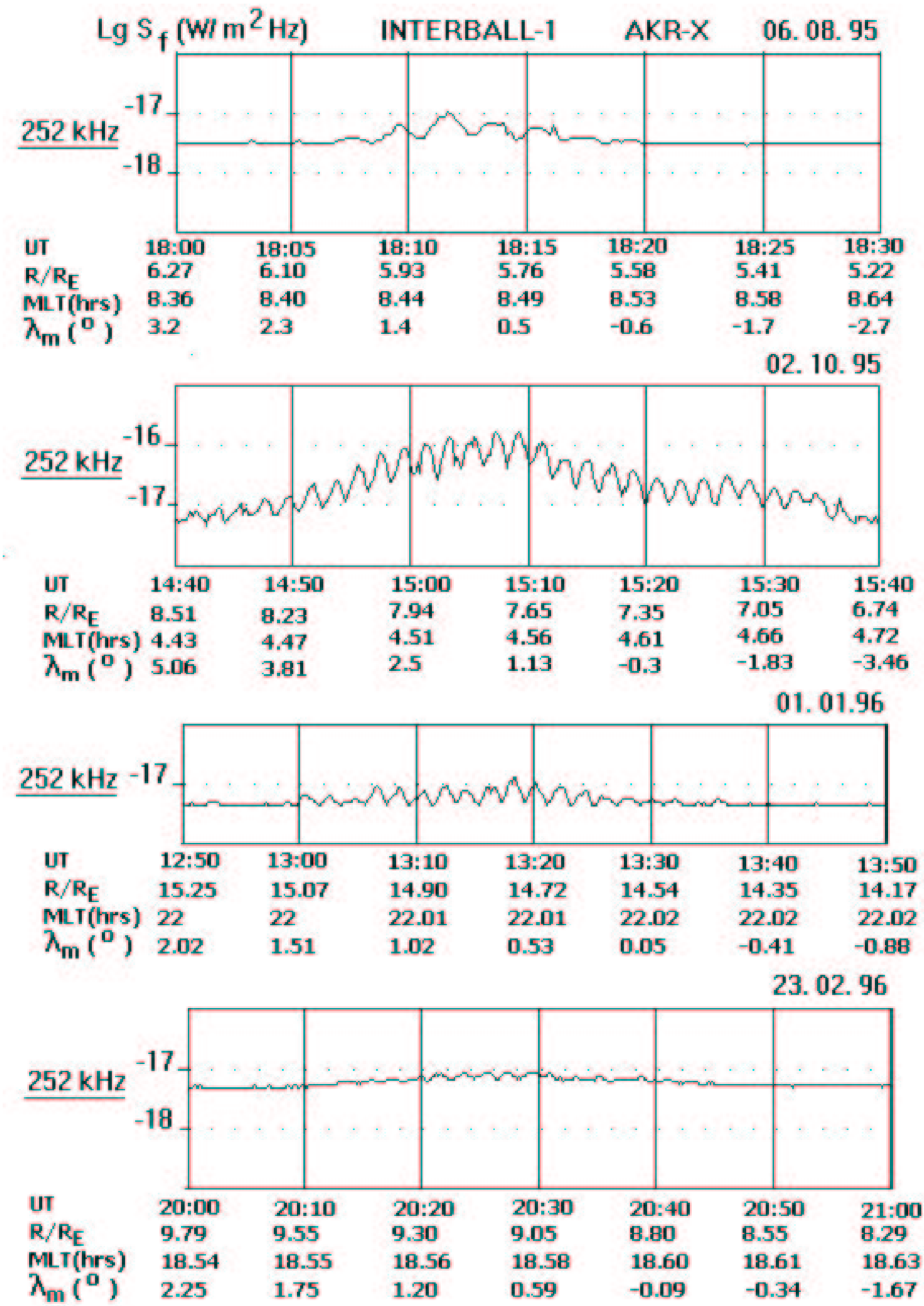

Figure 6: Examples of "continuum" emission observed at 252 kHz at the time of the INT–1 satellite passage through the magnetic equator, at the inbound part of the orbit.

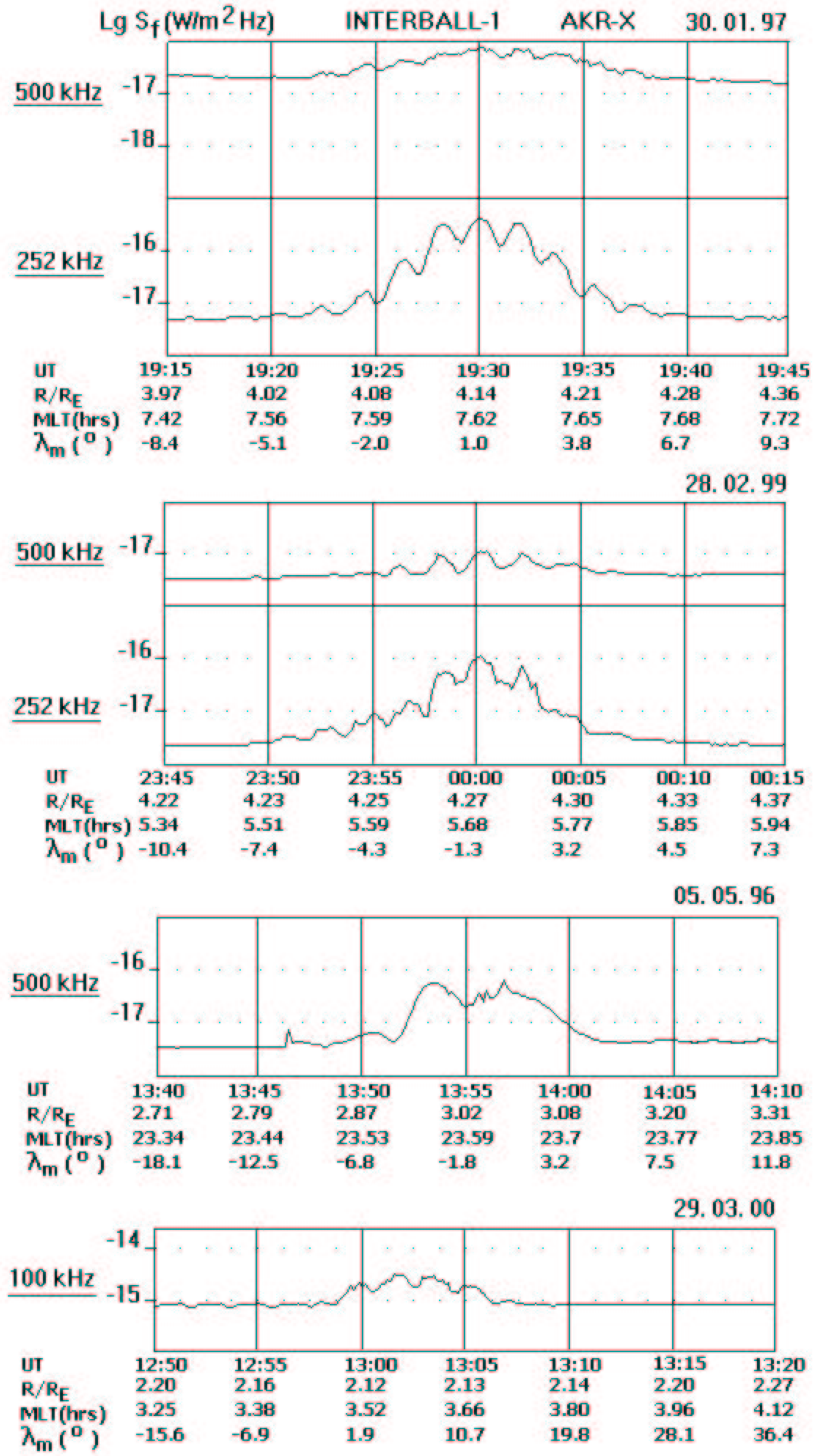

Figure 7: Examples of rare events of simultaneous registration of kilometric "continuum" at frequencies 252 kHz and 500 kHz, and single events at frequencies 500 and 100 kHz.

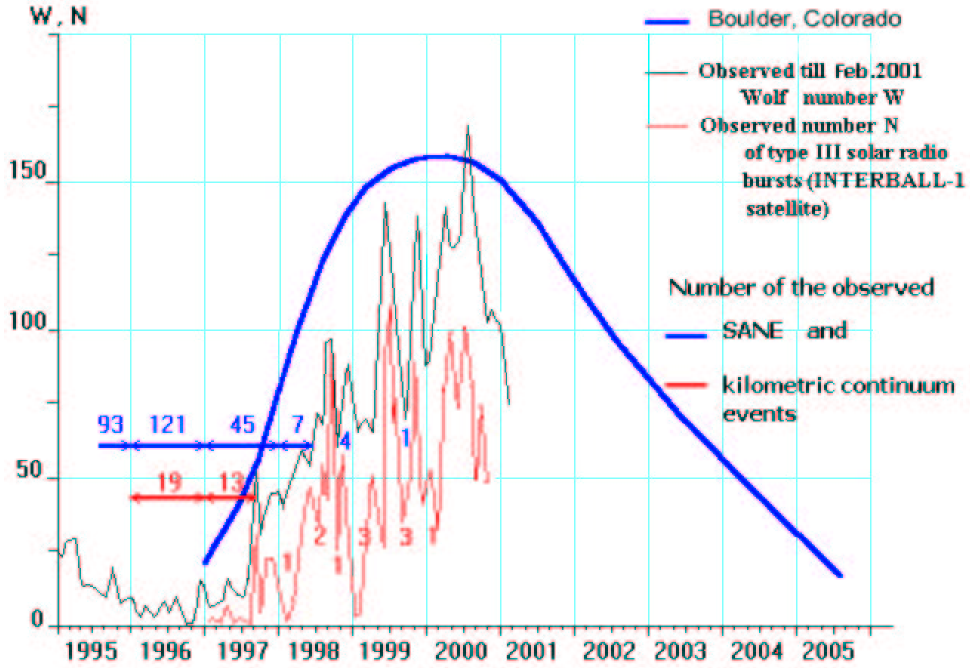

Figure 8: The dependence of the appearance of SANE and kilometric "continuum" events on a level of Solar activity presented by the change of Wolf's number W and the monthly number N of sporadic Solar radio bursts observed by INT–1 satellite.

3 Discussion

The INT–1 satellite observations of the emissions within the inner magnetosphere and the detection of emissions escaping from there, which propagate close to the plane of the magnetic equator, confirm the presence of kilometric "continuum" as detected by GEOTAIL. Z– and LO–modes of electromagnetic emission were registered in a frequency range of 100–1500 kHz. The transition of the LO–mode where it couples with the Z–mode (in the density gradient of the magnetized plasma; in the "window") to the escape out of the inner magnetosphere, was also observed. Mosier et. al [1973] using IMP–6 satellite observational data detected and discussed fixed frequencies determined "resonant" regions and the existence of RX, LO and Z–modes in the magnetized plasma density gradient in the terrestrial plasmasphere. Our observations of the coupling regions show that in these sources of "continuum" the signal has a rather noisy character corresponding to an impulsive character of the electrostatic emissions, which is a cause for the appearance of the Z–mode. In the coupling region as shown by Kurth [1982] in the coupling region the transition of the Z–mode to the LO–mode and back shows a pronounced impulsive character.

At times of a quiet Sun in 1995–1997 very narrow beams of kilometric "continuum" were observed, at least at 252 kHz (see Figure 4). This supports the theory of linear mode conversion (wave coupling through the "window") as suggested by Jones [1976, 1982].

Figure 8 shows the Solar activity effect on the appearance of escaping non–thermal "continuum" (subauroral (SANE) and kilometric) emissions. Besides variations of the Solar spots characteristic (Wolf's number, W), the variations of the monthly number of Solar radio bursts (N) observed by the INT–1 satellite is also presented. It can be seen that both curves (for W and N) are practically identical, but the curve of Solar bursts number has deeper depressions. With these depressions (apparently the periods of "stabilization" towards quiet Solar wind) the appearance of rare events of "continuum" are connected. In 1996 GEOTAIL detected about 100 events of kilometric "continuum". Our observations of SANE in 1996 resulted in approximately the same number of events (see Figure 8). INT–1 observations in 1996 detected 19 kilometric "continuum" event from 87 perigee registrations. This is a non-negligible probability of detection of this emission at times when INT–1 was in the correct location with regard to the magnetic equator. This is also in agreement with GEOTAIL data and the conclusion is that these emissions are not rare or unusual because they are observed between about 10 to 30% of the time of correct satellite position.

Figure 8 demonstrates that both discussed emissions show a large number of events during the years of low Solar activity and a sharp decrease of the observed events with the increase of Solar activity.

4 Conclusion

The INTERBALL–1 observations confirm the presence of the kilometric "continuum" emission recently detected by GEOTAIL [Hashimoto et. al, 1999b]. The peculiarities of this emission in the region of its origin and the character of beaming near the Earth were considered from INTERBALL-1 observational data. Subauroral and kilometric "continuum" are observed around the time of minimum Solar activity and are practically absent at times of its maximum. This means that the mechanism of the suppression of "continuum" emission is connected with the state of the Solar wind, whose strength and variations in time may be a cause for disturbances even of inner magnetospheric regions, where kilometric and subauroral non–thermal emissions are originated.

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